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Anomalous Diffraction Approximation Limits

Gorden Videen and Petr Chýlek

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Anomalous Diffraction Approximation Limits

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Abstract

It has been reported in a recent article that the anomalous diffraction approximation (ADA) accuracy does not depend on particle refrative index, but instead is dependent on the particle size parameter. Since this is at odds with previous research, we thought these results warranted further discussion.

The anomalous diffraction approximation (ADA) of van de Hulst (1981) provides a method by which gross scattering properties (scattering efficiencies and albedo) can be rapidly obtained. The primary assumption used to derive the approximation is that the scattering particle is soft; i.e., $|m-1| \ll 1$. In a recent article, Liu, Jonas, and Saunders (1996) reported that "the ADA accuracy depends mainly on the particle size parameter and is not sensitive to the condition of $|m-1| \ll 1$." Since this is at odds with several recently published studies (Mitchell and Arnott, 1994; Ackerman and Stephens, 1987; Evans and Fournier, 1996; Chýlek and Klett, 1991; and Chýlek and Videen, 1994), we felt that this statement warranted further clarification. There are two points to consider: First, the ADA produces more accurate results in the geometrical-optics (short-wavelength) limit. And second, the accuracy is independent of the particle refractive index (as proposed by Liu, Jonas, and Saunders, 1996).

The first point (the accuracy increases in the geometrical-optics limit) is not surprising. It is well-known that for large particles, the extinction efficiency approaches 2. This is illustrated in figure 1(a), which shows the extinction efficiencies plotted as a function of size parameter $x = 2\pi r/\lambda$ for a sphere of radius r. The extinction approaches zero as the radius approaches zero. As the radius increases, bringing the sphere into the resonance region, structure appears in the Mie extinction curves, which is beyond the capacity of the ADA to replicate. As the radius further increases, the oscillations gradually die, approaching the final, geometrical-optics limit. Since the ADA also approaches the proper, geometrical-optics limit, it is no surprise that the extinction efficiency accuracy increases. The accuracy of the absorption efficiency can similarly be explained. As the particle size increases, any light incident upon the particle will be absorbed (assuming nonzero absorption and a soft particle). The absorption efficiency must therefore approach unity for an absorbing soft particle. The Mie and ADA absorption efficiencies are shown as a function of sphere size parameter in figure 1(b). For the soft particle ($m = 1.1 + 0.01i$) having some absorption, the absorption approaches unity in the geometrical-optics limit.

The peculiar aspect of the investigation by Liu, Jonas, and Saunders (1996) is their claim of the lack of any accuracy dependence on the refractive index. This aspect can be understood when we consider the refractive indices of the particles in their study. They concentrated on ice particles through much of the ultraviolet (UV), visible, and infrared (IR) spectra. The value of the ice refractive index changes drastically throughout this range (as demonstrated in fig. 1 of Liu et al's report). However, for only a

couple (relatively narrow) spectral bands, the condition $|m-1| \ll 1$ holds ($\lambda \sim 2.8\ \mu m$, $10\ \mu m$). In these bands, the deviations of the ADA results from those given by Mie theory are less than 10 percent; whereas, in the other regions, the errors are typically much greater than 10 percent and sometimes even over 100 percent of the actual value. Unfortunately, these small regions of applicability only represent a small percentage of the entire spectrum and apparently went unnoticed in their analysis. As illustrated in figure 2, a strong accuracy dependence exists on particle refractive index as long as the particle remains sufficiently soft. Figure 2 shows the percent errors in the (a) extinction and (b) absorption efficiencies as a function of size parameter x for three different refractive index values. For real refractive index $m_r = 1.1$, the errors decrease in the small- and large-wavelength regions and can be quite substantial (10 to 30 percent) in the resonance region. Figure 2 illustrates that as m_r is further increased, the percent of errors become increasingly large as to be impracticable. Indeed, this is because of the particles themselves being well outside the bounds on refractive index for which the approximation was derived. The ice refractive index has an even wider range of values than is illustrated in figure 2. The associated errors resulting from the ADA calculations are so large that they become meaningless.

Figure 1. Mie and ADA (a) extinction and (b) absorption efficiencies as a function of sphere size parameter for three different refractive indices. Note that the three ADA absorption efficiencies overlap for spheres having the same imaginary part of the refractive index.

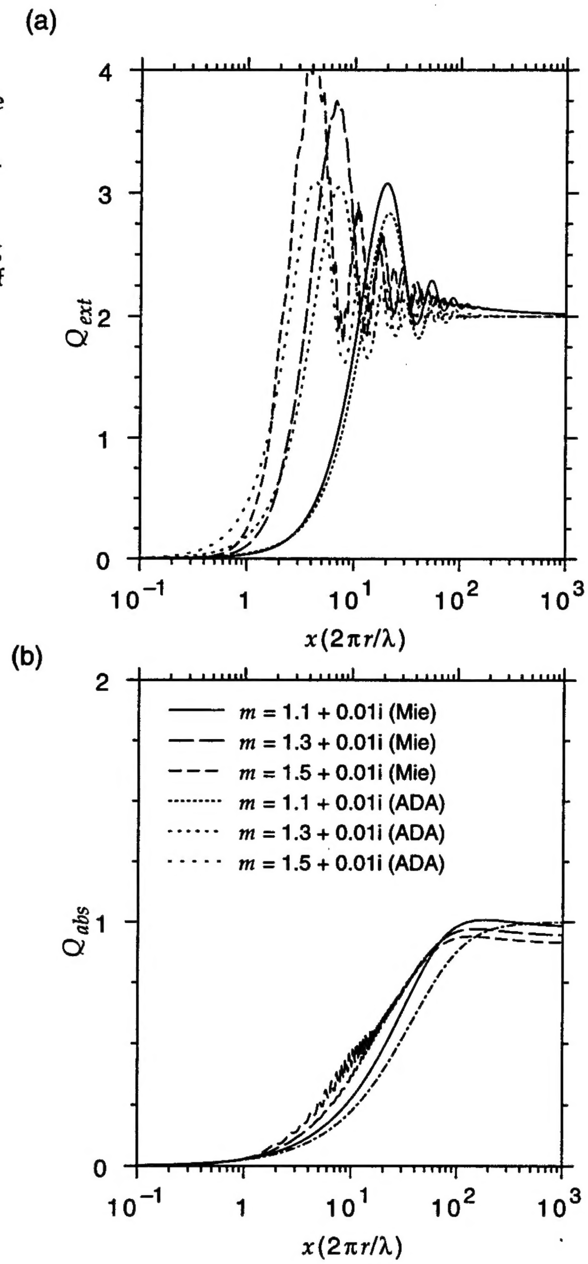
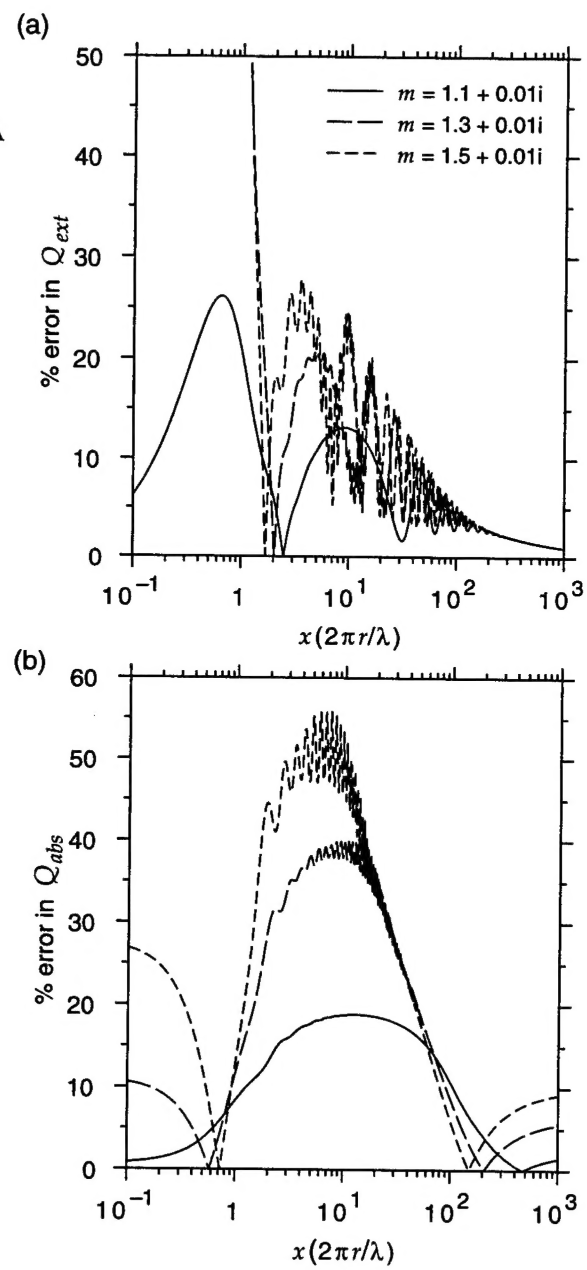


Figure 2. Percent error in (a) Q_{ext} and (b) Q_{abs} defined as the absolute value of the difference between the Mie and ADA extinction efficiencies divided by the Mie extinction efficiency.



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It has been reported in a recent article that the anomalous diffraction approximation (ADA) accuracy does not depend on particle refrative index, but instead is dependent on the particle size parameter. Since this is at odds with previous research, we thought these results warranted further discussion.

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